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Multi-gigabit analog equalizers for plastic optical fibers

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ABSTRACT

Two new CMOS analog continuous-time equalizers for high-speed short-haul optical fiber communications are presented in this paper. The proposed structures compensate the limited bandwidth-length product of 1-mm SI-POF channels (45 MHz · 100 m) and have been designed in a standard 0.18-μm CMOS process. The equalizers are aimed for multi-gigabit short-range applications, targeting up to 2 Gb/s through a 50-m SI-POF. The prototypes operate with a single supply voltage of only 1 V and overcome the severe limitations suffered by the widely used degenerated differential pair due to the low supply voltage.

1. Introduction

A growing interest exists today in step-index polymer optical fiber (SI-POF) because it represents an attractive transmission medium for high-rate data transmission over short distances. In short-haul communications, standard 1-mm SI-POF offers certain advantages over glass optical fiber (GOF): (i) greater flexibility, and resilience to bending, shock, and vibration, (ii) simpler and less expensive components, (iii) simplicity in handling and connecting (POF diameters are 1 mm compared with 8–100 μm for glass), (iv) efficient in terms on power of transceivers, and mainly, (v) overall lower cost [1,2].

For these reasons, the reliability of 1-mm SI-POFs was demonstrated in commercially available solutions both in industry and home networking at speeds up to 100 Mb/s over 50-m length and in automotive environments up to 150 Mb/s: Media Oriented Systems Transport (MOST) [3]. In fact, the goal set by some operators is to outperform the copper-based and all-radio-based solutions in the future [4]. But, as consumers demand more multimedia services requiring higher transmission speed, more effort is put into the development of high speed POF solutions. For example, the EU 7th Framework Program funded project “POF-Plus” [5] is dedicated to the development of a practical POF solution for Gigabit Ethernet to deliver a high-speed digital signal to in-building and in-house networks at a global cost below existing alternatives.

The extreme simplicity of POFs comes at the expense of lower transmission capacity with respect to GOFs. The main disadvantage of the SI-POF is the strong mode dispersion which limits the bandwidth-length product up to 45 MHz · 100 m [6]. This small bandwidth, unsuitable for gigabit communications, limits the maximum binary data rate which can be properly transmitted through SI-POF, since when the data rate is higher than the bandwidth of the channel, intersymbol interference (ISI) appears and affects the bit error rate (BER) of the whole communication system.

Different strategies can be used for reaching gigabit transmission over POF links. For example, more expensive graded-index POF (GI-POF) which reduce the POF penalties [7,8], or more elaborate modulation formats [9] that exploit the bandwidth better than the simple NRZ modulation at the expense of a more complex and power-hungry electronics. Because we are looking for a simple and cheap communication system, it is preferable to use equalization of the signal instead. The equalizer should provide the inverse frequency response of the channel to achieve a global response of the channel-equalizer combination flat over the frequency region in question.

In a practical transmission system, the exact characteristics of the channel are not known a priori and they can vary significantly. Temperature, material properties, length of the fiber and other kinds of effects (connectors, bends, etc.) can cause the bandwidth of the fiber to change substantially [10,11]. For example, Fig. 1 shows the dependence with the length of the frequency response of a Mitsubishi GH SI-POF [12]. Therefore, it is highly desirable to design an adaptive equalizer to compensate for the variation of the characteristics of the channel with all these effects. Otherwise, it would result in overcompensation or subcompensation increasing the bit error rate.

The channel equalizer can be included either into the transmitter and/or into the receiver. The implementation of the transmitter equalizer is relatively easier than that of the receiver

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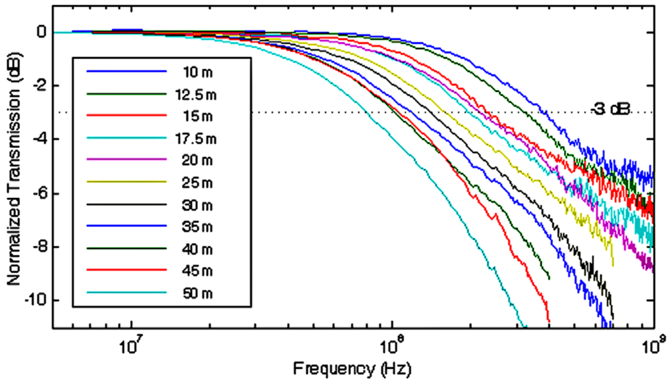

Fig. 1. Normalized frequency response of different lengths of SI-POF (Mitsubishi GH).

equalizer [13,14]. However, the adaptability degree would be very low and the power consumption would increase [11]. Consequently, receiver equalization is preferable, with optional pre-emphasis at the transmitter [15].

Receiver equalization processing can be categorized into two methods: discrete-time and continuous-time approaches. Discrete-time equalizers require clocks and high bandwidth sample-and-hold circuits working in the tens of gigahertz range. To avoid using these, a continuous-time equalizer can be used, as a good trade-off for low-power high-speed applications, requiring less complexity and smaller area than discrete-time or purely digital approaches [16,17].

Based on these reasons, we have designed two low-voltage low-power continuous-time adaptive equalizers to compensate for the limited bandwidth of POF channels. We have chosen an architecture suitable for fabrication in a low-cost standard 0.18-µm CMOS technology and adequate to achieve reliable data communications at 2 Gb/s including the equalizer in a receiver front-end architecture [18].

The paper is laid out as follows. Section 2 shows the main blocks of the proposed adaptive equalizer, where we have focused our attention on the equalizer architecture. Two different topologies for the line equalizer are proposed and compared with the conventional degenerated differential pair based equalizer. The most important post-layout simulated performances are summarized in Section 3. Finally, conclusions are drawn in Section 4.

2. Circuit design

2.1. Architecture

The most widely used continuous-time adaptive equalizers are based on time domain techniques [19,20]. After feed-forward equalization, the signal is applied to a slicing comparator. A servo loop provides an error signal proportional to the difference between the slicer input and output slopes. Unfortunately, the use of the slicer would limit the maximum speed [21]. Other continuous-time equalizers use the spectrum-balancing technique, which can obviate the need for an extremely high slew-rate and power-hungry comparator as the decision mechanism [21,22].

Consider ideal random binary data with non-return-to-zero (NRZ) code. The normalized spectrum, $S(f)$, can be expressed as

$$S(f) = T_b\left[\frac{\sin(\pi f T_b)}{\pi f T_b}\right]^2 \tag{1}$$

where T_b denotes the bit period of the data stream.

This signal can be decomposed into two parts with equal power, as shown in Fig. 2. This way, by performing a comparison between the low and the whole frequency components, we can determine if the equalizer output is under or over compensated and then generate an appropriate control signal to adjust the boosting of the equalizer.

Thus, we are able to obtain an error signal to control the equalizer, using the block diagram shown in Fig. 3. We use a low-pass filter and a high-pass filter to implement the power spectrum comparator. Therefore, we can compare the power between the low and high-frequency portions of the signal. Some authors use two band-pass filters, but these consume much more power [23].

In this paper, we have focused our attention on the line equalizer block without the adaptive feedback loop. Two new low-voltage continuous-time equalizers are proposed. The first one is based on the current-mode operation which, at least theoretically, may provide some benefits: low voltage operation, wide dynamic range, free from slew-rate limitations and wide bandwidth [24]. The second one is based on the voltage-mode operation and is simpler than the first one. Both follow the typical structure of a split-path scheme with a gain path and a high-frequency boosting path [16].

In future works, the different stages of the adaptive equalizer (line equalizer, power spectrum comparison filters, rectifiers and error integrator) will be implemented by using the g_m-C technique [25,26], which is coherent with low power requirements, sufficient dynamic

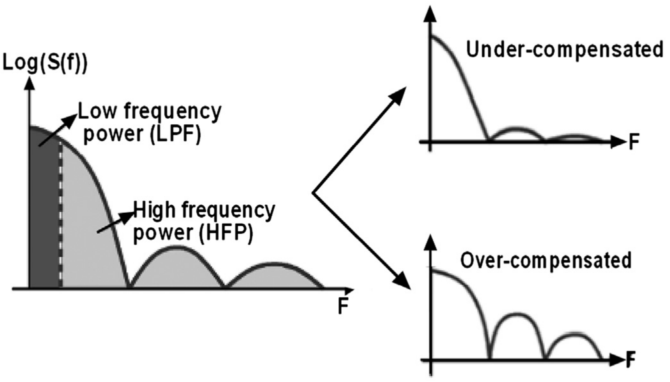

Fig. 2. Spectrum of an ideal random sequence and the effect of different compensations.

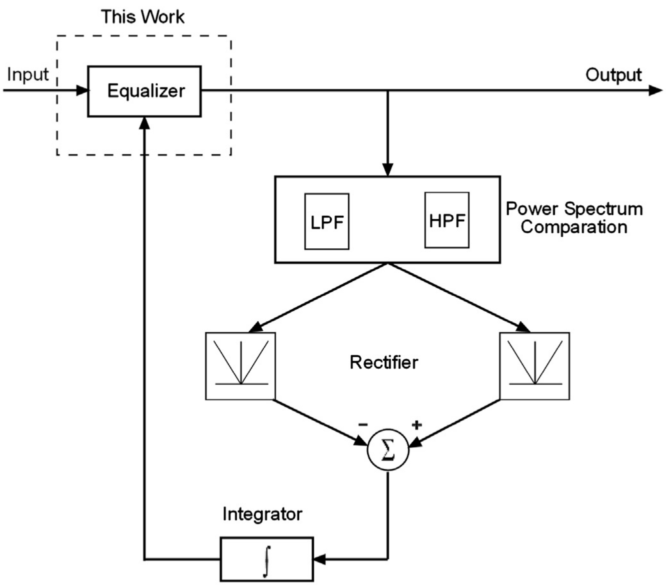

Fig. 3. Block diagram of an adaptive equalizer based on the spectrum-balancing technique.